U.S. DEPARTMENT OF ENERGY | Nuclear Energy

FC 2: Advanced Fuels

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DOE-NEUP FY2017 Webinar

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U.S. DEPARTMENT OF ENERGY

Nuclear Energy

The FCRD Advanced Fuel Campaign is tasked with development of near term accident tolerant LWR fuel technology and performing research and development of long term advanced reactor fuel options.

Advanced LWR Fuels with enhanced performance, safety, and reduced waste generation

Advanced reactor fuels with enhanced proliferation resistance and resource utilization

Capability Development for Science-based Approach to Fuel Development

- Advanced characterization and PIE techniques
- Advanced in-pile instrumentation
- Separate effects testing
- Transient testing infrastructure

Multi-scale, multi-physics fuel performance modeling and simulation

University R&D plays an important role in advanced nuclear fuels and materials principally through the NEUP program

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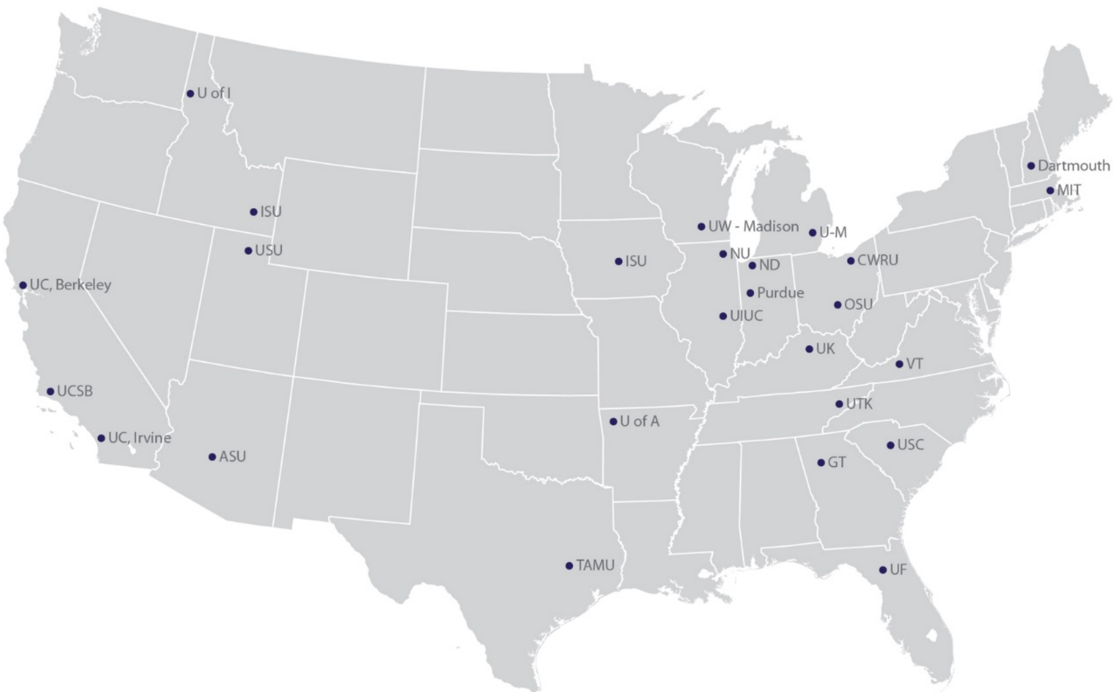
- **Typically > 30 projects in a given year in AFC**
  - 7 awarded in FY2016

- **Large number of lead and collaborating universities**



Advanced Fuels Campaign

NEUP Nuclear Energy University Programs
U.S. Department of Energy

FC 2.1 - Reactor pool-side non-destructive characterization techniques for advanced fuel concepts

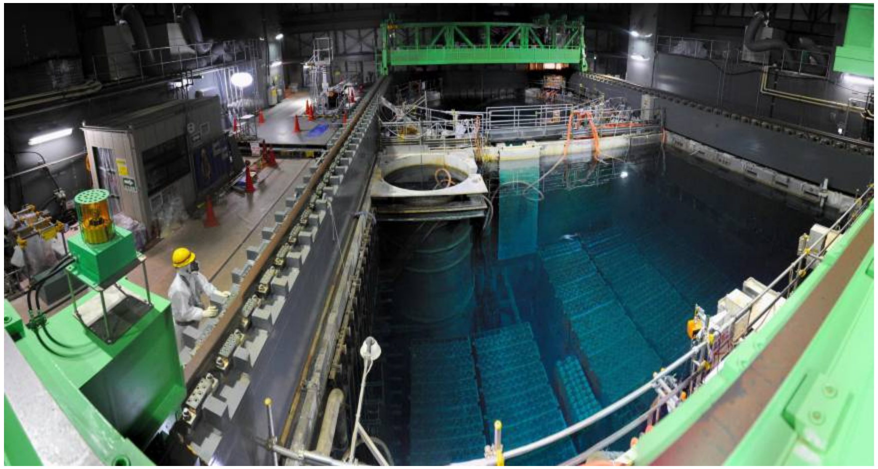
Federal Manager: Ken Kellar

Technical POC: Jon Carmack (INL)

- **Requests are sought for advanced non-destructive characterization techniques for advanced fuel (LWR ATF and advanced reactor fuel) that can be applied pool-side to a reactor, such as the Advanced Test Reactor, to provide characterization of irradiated fuels. Currently, irradiated fuel removed from an operating reactor or from a test reactor irradiation experiment is handled in a water pool environment. Advanced characterization techniques are sought that can provide information elucidating the physical condition, geometry, and general state of the nuclear fuel and cladding, with a particular focus on characterization of internal features and chemistry at the pool-side.**

Novel pool-side nuclear fuel experiment characterization techniques

- **Traditional technologies for pool-side inspections:**
  - Visual
  - Eddy current
  - Ultra-sonic
  - Gamma and neutron radiography
- **Desired characterization techniques (for example):**
  - Non-contact dimension and geometry
  - Fuel internal structure
  - Fuel internal chemistry



We are interested in novel technologies that will allow us to non-destructively characterize irradiated fuel experiments without removing the fuel from a pool-side environment (i.e., inspect a fuel experiment pool-side and then re-insert in a test reactor position).

FC 2.2 - Extreme performance metal alloy cladding for fast reactors

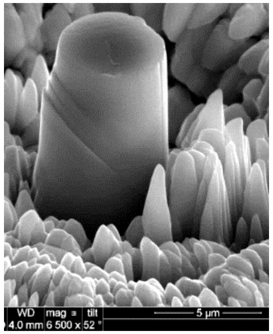
Federal Manager: Janelle Eddins

Technical POC: Stuart Maloy (LANL)

- **Requests are sought for a new out-of-the-box extreme performance metal alloy cladding concept. The new proposed concept should have the potential to achieve extreme transmutation fuels performance conditions; namely, for fast spectrum reactors, propose a cladding that can achieve 60% burnup and 600 dpa (in iron) or greater, for prototypic temperatures up to 700C. Proposals may consider variations from existing alloys. Proposals must recognize the gaps to be overcome, and propose activities that will prove feasibility of their concept in comparison to existing cladding concepts. Proposals that provide a method to prove irradiation performance of their concept will be given highest priority.**

High Dose Advanced Reactor Cladding Materials

- **Current Program Focus**
  - Qualifying HT-9 to radiation doses >250 dpa
    - Previous work on HT-9 shows improved ductility after low temperature irradiation
    - Four new heats of HT-9 were produced with controlled interstitial content
  - Developing Advanced Radiation Tolerant Materials (Oxide dispersion strengthened steel)
  - Using ion irradiations to assess high dose response of candidate fast reactor cladding and duct materials
- **Some advanced reactor concepts desire to irradiate fuels to very high burnup**
  - enabling use in reactor for decades and reducing frequency of fuel replacement
- **These concepts require extreme advances in nuclear fuel as well as cladding**
- **In this request, research is requested specifically related to development of advanced metal alloy cladding for these extreme fuels**



Micro compression testing performed on ion irradiated HT-9 showing localized slip

Multiple tubes produced by hydrostatic extrusion on heat of 14YWT (FCRD-NFA1) shown above.

FC 2.3 - Critical Heat Flux (CHF) for Accident Tolerant Fuels (ATF)

Federal Manager: Frank Goldner

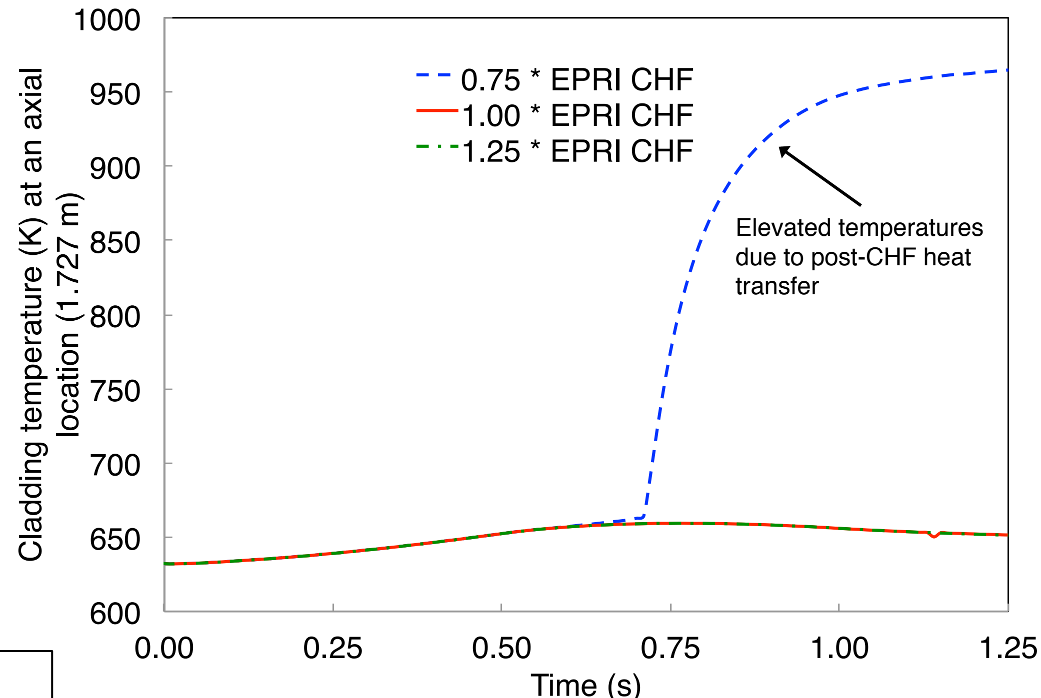
TPOC: Jon Carmack (INL)

- **Proposals are encouraged for separate effects studies leading to enhancements in thermal modeling and simulation of ATF fuel technologies. For proposed ATF cladding, determination of CHF under PWR and BWR conditions that results in departure from nucleate boiling (DNB) or dry out respectively, is intended**
- **Proposed efforts should focus on separate effect experiments but be tightly coupled with modeling, simulation, and validation efforts to study the impact of potential ATF cladding materials on CHF, during normal operation as well as in off-normal conditions. Given the near-term objective of the ATF program, model/ correlation outputs should be compatible with 'industry standard' state-of-the-art modeling tools and should also explain applicability to modeling and simulation tools currently in use or under development by DOE-NE. The proposals should support lead fuel assembly or lead fuel rod irradiations by investigating relevant ATF fuel and cladding thermal limits and design constraints.**

FC 2.3 Critical Heat Flux for Accident Tolerant Fuels

- **Surface wetting properties impact the critical heat flux**
  - Departure from nucleate boiling in PWRs and dry out in BWRs
- **Significant for defining safety limits as well as the high temperature phase of RIA and other transients**
- **Initial wettability property measurements indicate CHF may be different for candidate ATF cladding materials and coatings**

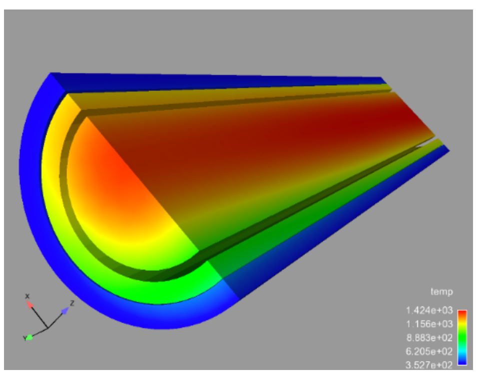
Proposed efforts should focus on experiments but include thermal hydraulics and neutronics modeling, simulation, and validation efforts to study the potential impact of ATF cladding materials and/or coatings on safety limits and transient and accident behavior



Example analysis showing potential impact of changes in CHF on peak cladding temperature for example power ramp transient

Key Items to Consider

- **Must show relationship to elements of the Advanced Fuels Program**
  - Priority given to proposals that support LWR accident tolerant fuel and fast reactor fuel concepts under study by FCRD
- **Review previous NEUPs to avoid duplication of activities**
- **Include reasonable timelines and deliverables**
- **Proposals tying experimental activities with modeling will be given higher priority**
  - Should support codes and models being developed by FCRD and NEAMS



Contact Information

- **Federal Program Managers:**
  - Ken Kellar, kenneth.kellar@nuclear.energy.gov
  - Frank Goldner, frank.goldner@nuclear.energy.gov
  - Janelle Eddins, janelle.eddins@nuclear.energy.gov
- **AFC National Technical Director: Jon Carmack**
  - jon.carmack@inl.gov
- **AFC Advanced Reactor Core Materials Lead: Stuart Maloy**
  - maloy@lanl.gov
- **Please review previous fuel related awards on www.neup.gov.**

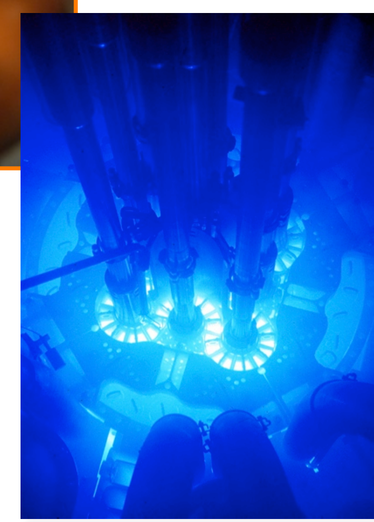
Background Information

Advanced Reactor Fuels Development

- **Scope:** Advance the scientific understanding and engineering application of fuels for use in future fast-spectrum reactors; includes: 1) support for driver/ startup fuel concepts, and 2) fuels for enhanced resource utilization (including actinide transmutation).

- **Domestic R&D focused on metallic fuel containing minor actinides**

- **Metallic Fuels Technology**
  - Fuel Fabrication/Fabrication Development
  - Fuel Optimization/Characterization
  - Fuel Feedstock Preparation
  - Cladding/Core Materials Development
  - Irradiation Testing and Post-irradiation Examinations
  - Fuel Modeling Support



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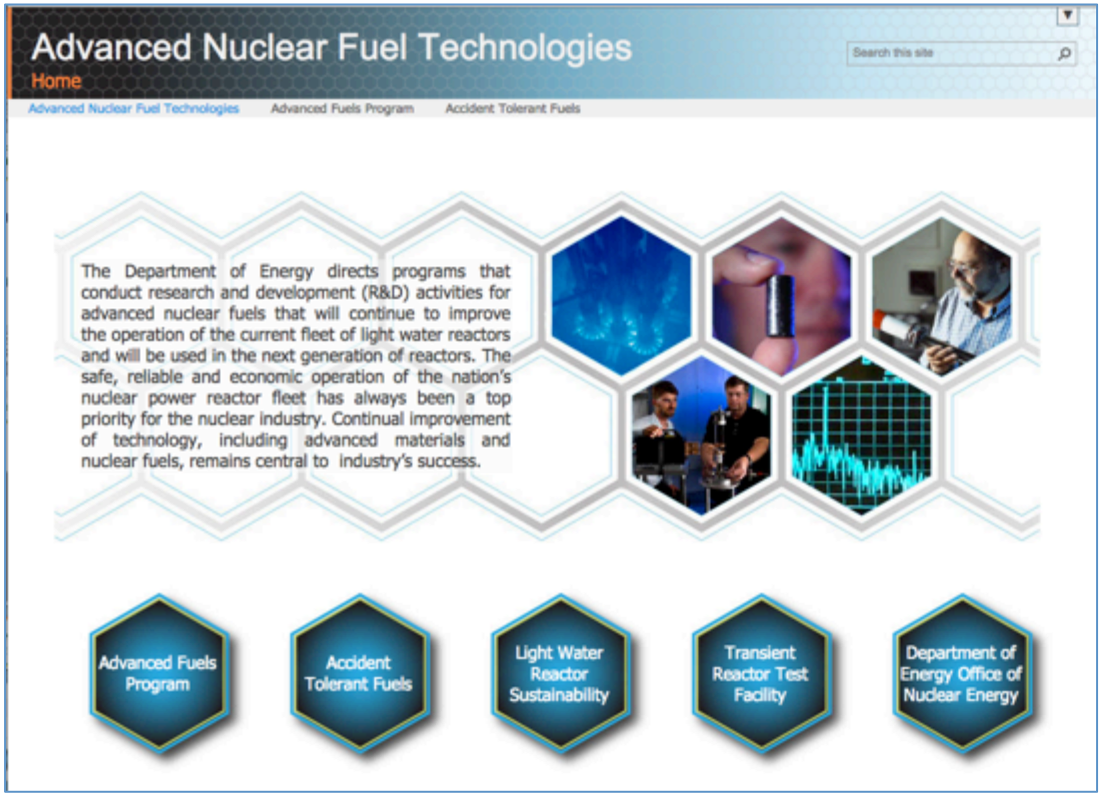
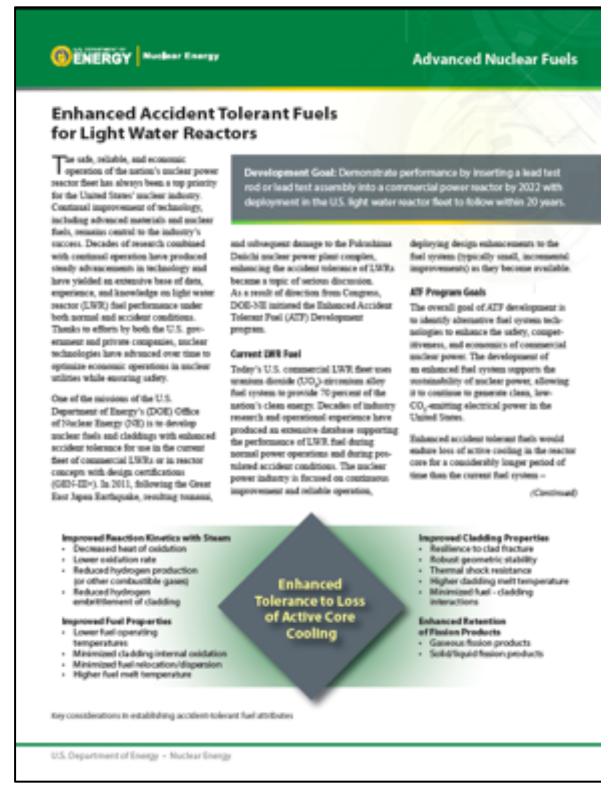
Advanced Fuels Website
https://nuclearfuel.inl.gov



Accident Tolerant LWR Fuel Information Sheet



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Advanced Nuclear Fuels

Enhanced Accident Tolerant Fuels for Light Water Reactors

Development Goal: Demonstrate performance by inserting a lead test rod or lead test assembly into a commercial power reactor by 2022 with deployment in the U.S. light water reactor fleet to follow within 20 years.

The safe, reliable, and economic operation of the nation's nuclear power reactor fleet has always been a top priority for the United States' nuclear industry. Continual improvement of technology, including advanced materials and nuclear fuels, remains central to the industry's success. Decades of research combined with continual operation have produced steady advancements in technology and have yielded an extensive base of data, experience, and knowledge on light water reactor (LWR) fuel performance under both normal and accident conditions. Thanks to efforts by both the U.S. government and private companies, nuclear technologies have advanced over time to optimize economic operations in nuclear utilities while ensuring safety.

One of the missions of the U.S. Department of Energy's (DOE) Office of Nuclear Energy (NE) is to develop nuclear fuels and claddings with enhanced accident tolerance for use in the current fleet of commercial LWRs or in reactor concepts with design certifications (GEN-III+). In 2011, following the Great East Japan Earthquake, resulting tsunami, and subsequent damage to the Fukushima Daiichi nuclear power plant complex, enhancing the accident tolerance of LWRs became a topic of serious discussion. As a result of direction from Congress, DOE-NE initiated the Enhanced Accident Tolerant Fuel (ATF) Development program.

Current LWR Fuel

Today's U.S. commercial LWR fleet uses uranium dioxide (UO_2)-zirconium alloy fuel system to provide 70 percent of the nation's clean energy. Decades of industry research and operational experience have produced an extensive database supporting the performance of LWR fuel during normal power operations and during postulated accident conditions. The nuclear power industry is focused on continuous improvement and reliable operation, deploying design enhancements to the fuel system (typically small, incremental improvements) as they become available.

ATF Program Goals

The overall goal of ATF development is to identify alternative fuel system technologies to enhance the safety, competitiveness, and economics of commercial nuclear power. The development of an enhanced fuel system supports the sustainability of nuclear power, allowing it to continue to generate clean, low-CO_2-emitting electrical power in the United States.

Enhanced accident tolerant fuels would endure loss of active cooling in the reactor core for a considerably longer period of time than the current fuel system –

(Continued)

Improved Reaction Kinetics with Steam
- Decreased heat of oxidation
- Lower oxidation rate
- Reduced hydrogen production (or other combustible gases)
- Reduced hydrogen embrittlement of cladding

Improved Fuel Properties
- Lower fuel operating temperatures
- Minimized cladding internal oxidation
- Minimized fuel relocation/dispersion
- Higher fuel melt temperature

Enhanced Tolerance to Loss of Active Core Cooling

Improved Cladding Properties
- Resilience to clad fracture
- Robust geometric stability
- Thermal shock resistance
- Higher cladding melt temperature
- Minimized fuel - cladding interactions

Enhanced Retention of Fission Products
- Gaseous fission products
- Solid/liquid fission products

Key considerations in establishing accident-tolerant fuel attributes

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AFC Advanced Fuels Campaign

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FY16 NEUP AFC Related Project Awards

NEUP Project #	Title	PI	Lead Institution
16-10668	Microstructure experiments-enabled MARMOT simulations of SiC/SiC-based accident tolerant nuclear fuel system	Jake Eapen	NCSU
16-10221	Alloying agents to stabilize lanthanides against fuel cladding chemical interaction: Tellurium and Antimony studies	Jinsuo Zhang	Ohio State University
16-10667	A coupled experimental and simulation approach to investigate the impact of grain growth, amorphization, and grain subdivision in accident tolerant U3Si2 LWR fuel	Mike Tonks	Pennsylvania State University
16-10648	Microstructure, thermal, and mechanical property relationships in U and U-Zr alloys	Maria Okuniewski	Purdue University
16-10648	Oxidation and corrosion-resistant uranium silicide fuels	Jie Lian	RPI
16-10523	A science based approach for selecting dopants in FCCI-resistant metallic fuel systems	Indrajit Charit	Univ. of Idaho
16-10204	Phase equilibria and thermochemistry of advanced fuels: modeling burnup behavior	Ted Bessmann	Univ. of South Carolina

Recent Advanced Fuels Campaign Documents – Available on OSTI

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OSTI Document Links of Interest:

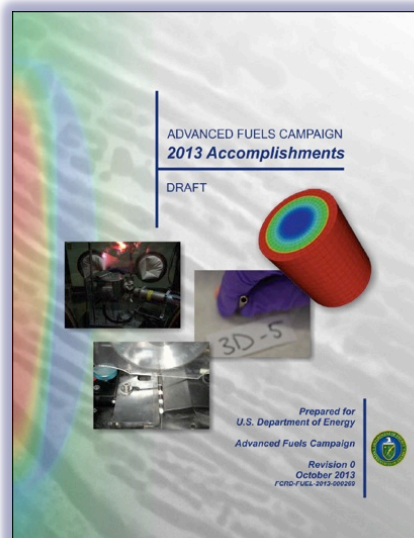
Overview of Accident Tolerant Fuel Program
http://www.osti.gov/scitech/servlets/purl/1130553

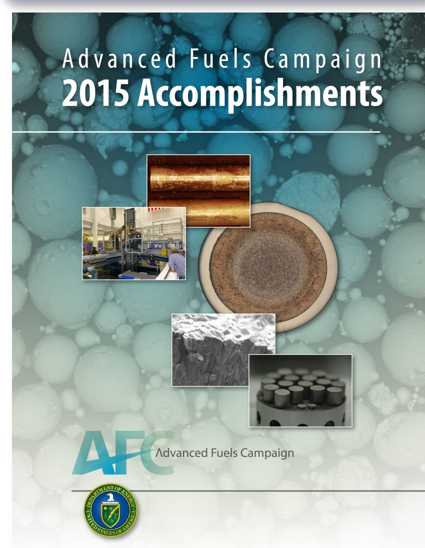
Accident Tolerant Fuel Performance Metrics
http://www.osti.gov/scitech/servlets/purl/1129113

2013 Accomplishments Report
http://www.osti.gov/scitech/servlets/purl/1120800

2014 Accomplishments Report
http://www.osti.gov/scitech/biblio/1169217

2015 Accomplishments Report
http://www.osti.gov/scitech/servlets/purl/1236849





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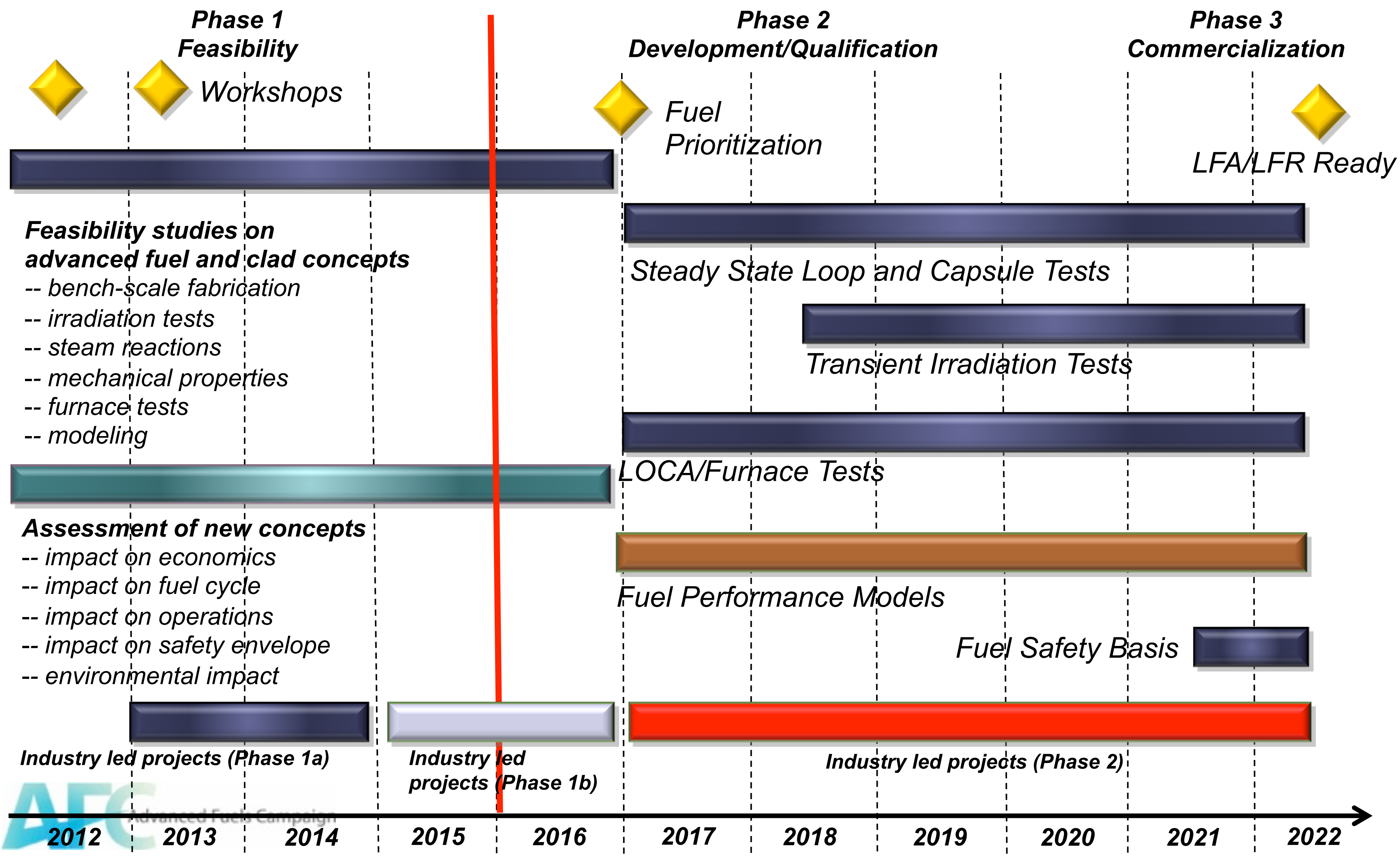
RD&D Strategy For Enhanced Accident Tolerant Fuels – 10 Year Goal



Feasibility Phase Produces a Wide Range of Promising Concepts (1 of 2)

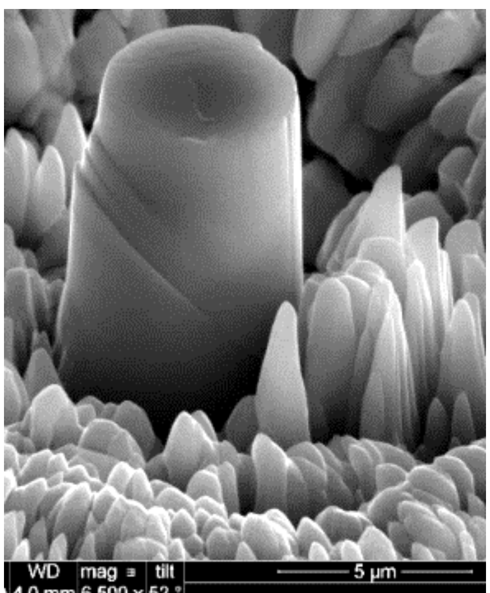
Fuel	Cladding
AREVA	
Chromium-doped UO_2 pellets	Chromium-coated zirconium
Composite UO_2 pellets (with SiC or diamond)	Silicon-carbide sandwich
UO_2 pellets	Coated molybdenum
Westinghouse	
U_3Si_2 pellets	Coated zirconium
U_3Si_2 pellets	Silicon-carbide coated zirconium
U_3Si_2 pellets	SiC/SiC composite
General Electric	
UO_2 pellets	FeCrAl alloy

Feasibility Phase Produces a Wide Range of Promising Concepts (2 of 2)

Fuel	Cladding
Pacific Northwest National Laboratory	
Uranium-molybdenum metal	Zircaloy or FeCrAl
Oak Ridge National Laboratory	
UO_2 pellets	SiC/SiC composite
Fully ceramic, microencapsulated	Zircaloy to FeCrAl or SiC
Los Alamos National Laboratory	
High-density ceramic composites (e.g., UN/U_3Si_2)	Focus is on fuels only.
Ceramic Tubular Products	
Focus is on cladding only.	SiC “TRIPLEX”

High Dose Testing and Analysis of Advanced Reactor Clad Materials

- Previous work on heat of HT-9 shows improved ductility after low temperature irradiation.
- Four new heats of HT-9 were produced: Two by Metalwerks and two by Sophisticated Alloys with controlled interstitial content. Ion irradiation and analysis is underway.
- Using ion irradiations to assess high dose response of candidate FR clad and duct materials.
- Oxide dispersion strengthened steel (FCRD-NFA1) is being produced into tube form using hydrostatic extrusion and pilger processing.
- Multiple international collaborations underway on ODS processing (Japan (CNWG), France (CEA))



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